Journal of Environmental Management 147 (2015) 175–183

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Measuring farm sustainability using data envelope analysis with principal components: The case of Wisconsin cranberry

Fengxia Dong [a], [*], Paul D. Mitchell [a], Jed Colquhoun [b]

[a] Department of Agricultural and Applied Economics, University of Wisconsin-Madison, 427 Lorch Street, Madison, WI 53706, USA
[b] Department of Horticulture, University of Wisconsin-Madison, 1575 Linden Drive, Madison, WI 53706, USA

ARTICLE INFO

Article history:
Received 9 May 2013
Received in revised form
12 March 2014
Accepted 18 August 2014
Available online 30 September 2014

Keywords:
Sustainability metric
Polychoric principal component analysis
Non-negative principal component analysis
Common-weight data envelope analysis

ABSTRACT

Measuring farm sustainability performance is a crucial component for improving agricultural sustainability. While extensive assessments and indicators exist that reflect the different facets of agricultural sustainability, because of the relatively large number of measures and interactions among them, a composite indicator that integrates and aggregates over all variables is particularly useful. This paper describes and empirically evaluates a method for constructing a composite sustainability indicator that individually scores and ranks farm sustainability performance. The method first uses non-negative polychoric principal component analysis to reduce the number of variables, to remove correlation among variables and to transform categorical variables to continuous variables. Next the method applies common-weight data envelope analysis to these principal components to individually score each farm. The method solves weights endogenously and allows identifying important practices in sustainability evaluation. An empirical application to Wisconsin cranberry farms finds heterogeneity in sustainability practice adoption, implying that some farms could adopt relevant practices to improve the overall sustainability performance of the industry.

1. Introduction

Though agricultural productivity has increased tremendously over the past decades, global food production must double between 2005 and 2050 to meet the demand of a growing population with increasing purchasing power (U.S. Department of Agriculture, 2010; Tillman et al., 2011). Agricultural intensification will be important for meeting this challenge, including continued crop genetic improvements, expansion and improvement of no-till agriculture, adoption of technologies and practices to improve nutrient and water use efficiency, and other land-sharing conservation practices on agricultural lands (Tillman et al., 2011; Ronald, 2011; Montgomery, 2007; Perfecto and Vandermeer, 2010). The concept of sustainability has been and will continue to be at the center of this debate and related efforts. Though a variety of definitions of agricultural sustainability exist, there is a general consensus that agricultural sustainability focuses on producing crops and livestock for human use while simultaneously pursuing environmental, economic, and social goals (e.g., National Research Council, 2010).

Consumers commonly express positive willingness to pay for products with sustainability attributes, but question the credibility of product claims (Blend and van Ravenswaay, 1999; Nimon and Beghin, 1999; Teisl et al., 1999; Onozaka and Mcfadden, 2011). To address this credibility problem and to begin documenting the current status of and improvements in agricultural sustainability, several sustainability indicators or standards are in various stages of development in the U.S. for different commodities.[1] These sustainability assessments or standards are typically very extensive, including many indicators for the environmental, economic, and social aspects of agricultural sustainability, such as practices or outcomes related to soil, water, nutrients, pesticides, energy, biodiversity, waste, rural community, farmer and employee welfare, and economic returns. For example, the whole farm

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* Corresponding author. Tel.: +1 608 262 7359.
E-mail addresses: fdong6@wisc.edu (F. Dong), pdmitchell@wisc.edu (P.D. Mitchell), colquhoun@wisc.edu (J. Colquhoun).

[1] Examples include the Field to Market FieldPrint Calculator (http://www.fieldtomarket.org/fieldprint-calculator/), the Stewardship Index for Specialty Crops (http://www.stewardshipindex.org/) and several sustainability tools developed by the Wisconsin Institute Sustainable Agriculture (http://wisa.cals.wisc.edu/sustainability-tools).

http://dx.doi.org/10.1016/j.jenvman.2014.08.025
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assessment developed by the Wisconsin Institute for Sustainable Agriculture collects information on use of over 200 practices.[2] The large number of indicators shows how comprehensive these assessments must be to describe and document the many aspects of agricultural sustainability on farms.

Given the extensive nature of most sustainability assessment tools and metrics, methods to integrate and aggregate the collected information in order to manage and to document sustainability improvements are of great interest, not only to farmers, but also to policy makers and other stakeholders. Thus, developing a composite indicator that combines information from these extensive sustainability assessments or standards seems particularly useful. At the farm-level, this composite indicator would inform individual farmers how their sustainability practices and/or outcomes compare to their peers and identify practices or outcomes that can help improve their sustainability. At the aggregate level, the properties of the distribution of all the composite indicators would describe how a farm population is performing as a whole and this performance could be tracked over time. Such information could be useful for developing and evaluating different policies and programs to help improve farm sustainability.

Some reject composite indicators because the weighting process is arbitrary (Sharpe, 2004) or because “work in data collection and editing is wasted or hidden behind a single number of dubious significance” (Saisana et al., 2005, p. 308). However, Saisana and Tarantola (2002) point out that composite indicators can summarize complex, multi-dimensional realities without dropping the underlying information base. Composite indicators are easier to interpret than a set of many separate indicators and facilitate communication with the general public and stake holders, including farmers who are primarily responsible for realizing agricultural sustainability. Moreover, concerns about the weighting process used by composite indicators and wasting or hiding data can be alleviated by choosing a non-subjective method that allows tracing a composite indicator score back to the original data.

Sustainability indicators can be classified as either outcomes or practices. Practice-based metrics document farmer adoption of various practices such as integrated pest management or soil nutrient testing, while outcome-based metrics measure or estimate various outcomes or consequences of farmer production practices, such as soil erosion rates or greenhouse gas emissions. Practice-based sustainability assessments are generally more popular among farmers because surveys are easy to complete and the data collection costs are lower. Such assessments commonly ask farmers to choose categorical rankings (never, rarely, sometimes, always) or binary indicators (yes, no) to measure their degree of adoption of practices. For example, asking for subjective assessments of how often a specific practice is used or whether or not it is used, rather than what percentage of acres or how many hours were devoted to a specific practice. Several studies exist on methods for generating composite indicators for farm sustainability (e.g., Gómez-Limón and Sanchez-Fernandez, 2010; Gómez-Limón and Riesgo, 2009; Reig-Martínez et al., 2011; Rigby et al., 2001). However, many of these methods use subjective weights or are not suitable for discrete (non-continuous) data such as collected by a practice-based sustainability assessment.

Our goal here is to describe and evaluate a method for constructing a composite indicator that addresses problems commonly arising for agricultural sustainability indicators. The method not only uses a statistical model to derive weights, but also is suitable for large correlated discrete data. As an empirical illustration, we apply the method to Wisconsin farms growing cranberries (*Vaccinium macrocarpum* Ait) to measure the intensity of sustainable practice adoption for each farm. We believe that the method is the first to combine non-negative polychoric principal component analysis (PCA) with common-weight data envelope analysis (DEA) to rank the performance of individual farms in terms of agricultural sustainability.

In the remainder of the paper, Section 2 describes Wisconsin cranberry sustainability and the data we use in this study. Following, Section 3 discusses common issues arising when using data envelopment analysis to construct agricultural sustainability composite indicators. Section 4 describes a method for transforming discrete data to become continuous and then generating a composite sustainability indicator that has weights derived by a statistical model. Section 5 presents the results and discusses how the composite indicators can help farmers and policy makers identify relevant practices in sustainability evaluation. And Section 6 concludes.

2. Wisconsin cranberry sustainability and data

In 2011, Wisconsin growers harvested almost 7,300 ha of cranberries, which produced almost 195 kiloton, or 58% of U.S. cranberry production and 45% of global cranberry production (U.S. Department of Agriculture, 2011; FAO, 2012). Cranberries are Wisconsin's largest fruit crop, accounting for almost 85% of the total value of fruit production in the state and contributing nearly $300 million annually to the state's economy and supporting approximately 3,400 jobs (Wisconsin State Cranberry Growers Association, 2011a; Arledge Keene and Mitchell, 2010). The U.S. exports about 25% of its annual cranberry production, with the United Kingdom and Germany as the major importers (Wisconsin State Cranberry Growers Association, 2011b).

Environmental sustainability of cranberry production generally focuses on management practices for water, nutrients and pests. Cranberry is a unique crop because of its special need for water during harvest and for pest control and plant protection during winter. This reliance on water makes a nutrient management plan to manage the amount, source, placement, form, and timing of the application of nutrients and soil amendments especially critical for maintaining water quality (Wisconsin State Cranberry Growers Association, 2012a). A well-developed nutrient management plan helps applied nutrients match cranberry nutrient needs and thus reduce environmental risk (Colquhoun and Johnson, 2010). A cranberry nutrient management plan encourages practices such as basing fertilizer inputs on soil tests and cranberry tissue tests, timing fertilizer applications for optimum uptake, and keeping complete and accurate nutrient management records (Colquhoun and Johnson, 2010).

Besides water quality, water availability is equally important in cranberry sustainability. A good irrigation management plan helps prevent unnecessary water losses and waste while still optimizing plant health, and usually includes calculating irrigation runtimes and monitoring soil moisture to set irrigation schedules in order to efficiently utilize water resources (Wisconsin State Cranberry Growers Association, 2012b). In addition, uniformity is critical to the irrigation system's application efficiency and crop yield. Poor uniformity not only can reduce yields from water stress and water logging, but also can increase nutrient losses when excess water leaches nutrients from the plant root zone, thus increasing fertilizer and pumping costs and reducing grower returns (Ascough and Kiker, 2002; Clemmens and Solomon, 1997).

A wide range of pests affect cranberries, including insects such as the blackheaded fireworm (*Rhopobota naevana* Hübner) and the cranberry fruitworm (*Acrobasis vaccinii* Riley), diseases such as

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[2] http://wisa.cals.wisc.edu/download/whole_farm/wholefarmcashgrainprotocol2-12.pdf.